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Experimental Determination of a Bulking Factor for Rock Embankment Construction - Phase II: Morrison Pit

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Abstract	The bulking factor is a relative measure of the change in volume (bulking) of a material from its in-situ condition following excavation, placement and compaction. In highway construction, a bulking factor for rock is used to estimate the quantity of broken, blasted rock from excavations available for construction of roadway embankments and other fills. A bulking factor was determined for a rock fill embankment constructed within the Morrison Pit using predominantly granite, felsic gneiss and marble breccia bedrock. The volume of the embankment was accurately surveyed after its construction. The embankment was then excavated and the mass of the materials was determined. The overall density of the embankment was calculated from these measurements and compared to the in-situ density of the bedrock source. The ratio of these two density measurements was used to obtain the bulking factor. A bulking factor of 1.376 was determined from this project. This was the second embankment constructed to examine rock bulking factors. The bulking factor determined from the first project was 1.353, which is documented in Materials Engineering and Research Report MERO-004. Based on these values, it was recommended to use a reduced bulking on future highway construction projects. A memo signed by the Chief Engineer of the Engineering Standards Branch was issued instructing highway designers to use a bulking factor value of 1.35 for all bedrock types when estimating rock fill quantities.
Key Words	bulk density, bulking factor, Canada, construction, embankments, gneiss, granite, highway, marble, rock fill, rock excavation
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Table of Contents

Table of Contents i
List of Tables ii
List of Figures iii
Executive Summary 1
Introduction 3
Background 4
Field Work 5
Site Location 5
Bedrock Geology 6
Embankment Design 6
Initial Survey – Original Ground 6
Embankment Construction 7
Intermediate Survey – Embankment Surface 7
Embankment Removal 7
Final Survey – Final Ground 8
Measurements 9
Embankment Volume 9
Embankment Mass 9
Embankment Density 10
Bedrock Density 10
Bulking Factor Calculation 11
Discussion 13
Conclusions 15
References 17
Appendix A: Figures 19
Appendix B: OPSD 201.010 31
Appendix C: Memo Sept 14, 2004 32
Appendix D: Published Rock Properties 33

List of Tables

Table 1: Calibration Data for VEI Millenium vs. Platform Scales 8
Table 2: Embankment Volume Measurements 9
Table 3: Mass measurements during removal 9
Table 4: Embankment Bulk Density (t/m^3) 10
Table 5: Bedrock Density 11
Table 6: Calculated Bulking Factor 11
Table 7: Summary of Rock Bulking Factor Projects 15

List of Figures

Figure 1 – Location of project area near Minden, Ontario. 20
Figure 2 – Location of Morrison Pit near Moore Falls, approximately 17 km south of Minden. 20
Figure 3 – Bedrock geology of the project showing locations of the rock cut used as a material source and the Morrison Pit (after Easton, 1992) 21
Figure 4 – Source material for the embankment was taken from bedrock excavated from this rock cut on Hwy 35. 22
Figure 5 – Initial construction of the test embankment began with a highly weathered granite-gneiss immediately north of the rock location shown in Figure 4 and Figure 7 22
Figure 6 – Close-up view of the weathered granite-gneiss shown above. This rock was used in construction of the access ramp during initial stages of the embankment construction. 23
Figure 7 – View of blasted rock at the site of excavation showing general block size distribution of the muck pile. 23
Figure 8 – Excavation of source materials using a CAT 330 BL backhoe into Volvo A25C rock truck. 24
Figure 9 – Materials were transported to the embankment construction site, end-dumped in a single lift and spread by bulldozer. 24
Figure 10 – View of partially constructed test embankment within Morrison Pit. Access ramp on the right is approximately 15m long 25
Figure 11 – Spreading of materials and grading was accomplished with a CAT D6R XL. Note segregation along leading outside edge of embankment. Blocks larger than 1 m diameter (1/3 height of embankment) were removed. 25
Figure 12 – Photocomposition of embankment near completion with approximate stations for scale 26
Figure 13 – View of embankment side slopes, graded to meet requirements of OPSD 201.010. 27
Figure 14 – Survey being conducted following completion of the embankment to calculate initial volume of materials. 27
Figure 15 – Removal of embankment by CAT 980G loader. Materials were weighed using on-board scales calibrated daily against the pit scales. 28
Figure 16 – Close-up of embankment removal. The operator recorded cumulative masses of each load. 28
Figure 17 – Embankment near complete excavation. Materials were removed as close to original ground elevation as possible. A final survey was completed to determine volume of materials removed. 29
Figure 18 – View of finished rock cut after final grading and hydro seeding. 29
Figure 19 – Histogram of individual dry density values of 74 random samples collected from the finished embankment. The average density of the samples is 2.703 t/m3. 30

Executive Summary

The bulking factor is a relative measure of the change in volume (bulking) of a material from its original in-situ condition to the volume of the same mass following excavation, placement and compaction. A bulking factor for rock is used by highway designers to estimate the quantity of broken, blasted rock from excavations that is available for the construction of roadway embankments and other fills.

A bulking factor was determined for a rock fill embankment built specifically for this purpose. The work was included as part of an MTO capital contract on Highway 35 near Minden, Ontario. The embankment was constructed within the Morrison Pit, located adjacent to the contract using predominantly granite, felsic gneiss and marble breccia bedrock excavated from within the contract limits. The volume of the embankment was accurately surveyed after its construction. The embankment was then excavated and the mass of the materials was determined. The overall density of the embankment was calculated from these measurements and compared to the in-situ density of the bedrock materials. The ratio of these two density measurements was used to obtain the bulking factor.

A bulking factor of 1.376 was determined from this project. This was the second embankment constructed to examine rock bulking factors. The bulking factor determined from the first project was 1.353, which is documented in Materials Engineering and Research Report MERO-004. Based on these values, it was recommended to use a reduced bulking on future highway construction projects. On September 14 2004, a memo signed by the Chief Engineer was issued instructing highway designers to use a bulking factor value of 1.35 for all bedrock types when estimating rock fill quantities.

Introduction

The "bulking factor" is defined as the ratio of the volume of material following excavation to the in-situ volume of the same material. In underground mining, a bulking factor is used to estimate excavated (bulked) rock volumes in order to manage the movement of materials in limited openings at depth. In open ground mining and aggregate production from quarries, the bulking factor is used to estimate storage space requirements for muckpiles and processed materials. When applied specifically to highways, a rock bulking factor is used as a design tool to balance quantities between rock excavation and rock fill required to complete a roadway to a given elevation as well as minimize costs associated with importing external material. Builders (contractors) may also use a bulking factor when planning cost estimates for the proposed work.

Limited information is available on specific rock bulking factors for highway embankment construction. Values reported in the literature are mostly from the mining and quarrying industries and apply only to volumetric increases of excavated materials and do not include additional changes that occur when the same material is subsequently placed as compacted fill. In most cases, bulking factors are not adjusted for the type of bedrock. Where it is desired to optimize construction such as rock fill dams, test sites may be constructed to obtain site specific bulking factors. However, these "experimental" determinations of bulking factor values are not published.

The Ministry of Transportation (MTO) conducted two separate experimental studies to determine bulking factors for different bedrock types. At each test site, measurements of the mass and volume of a full size embankment structure were determined under controlled conditions. A bulking factor was calculated by comparing the average density of each embankment with the density of the bedrock source used in its construction. The first embankment was built near Parry Sound, Ontario where a bulking factor of 1.353 was determined for the dense mafic gneiss bedrock found in this region. Detailed results on the construction and calculations related to this project are published in Materials Engineering and Research Office Report MERO-004 (Senior et al, 2003). A second rock fill embankment was constructed at the Morrison Pit as part of a capital construction project near Minden, Ontario, and is the subject of this report.

The information gathered from both test embankments has been used to establish a new bulking factor value for the design of highway facilities in Ontario, taking into account compaction of materials used in the fill. It is expected that this revised bulking factor will help improve design estimates and reduce construction costs, especially with large projects involving significant quantities of rock.

Background

A need for an accurate assessment of a rock bulking factor became apparent following the construction of new highway alignments for the expansion of Highways 400, 11, and 69 in northern Ontario in the late 1990's. This work involved several projects in the Parry Sound area that required numerous, deep rock cuts with individual contracts requiring excavation of more than 1,000,000 m^3 each.

On MTO construction projects, values for the rock bulking factor are set out in the Construction Design Estimating and Documentation Manual (MTO, 1991). This document identifies a value of 1.5 (volumetric expansion of 50%) for all bedrock types, other than for shale where a value of 1.2 is used (20% net volumetric expansion). These bulking factors were used in the design of the new highway alignments in northern Ontario as they had mostly provided satisfactory for previous MTO work. However, several shortfalls in available rock quantities on the new highway expansion projects occurred that were attributable to several factors, including poorly estimated bedrock surface and the need for additional material required for fill in deep swamps. Since the quantities of rock involved were much larger than previously experienced, the rock bulking factor was also identified as a potential contributing factor to the shortfalls.

With large quantities of material, it becomes extremely important to use an accurate bulking factor at the design stage in order to make better estimates of the amount of material available for construction. On MTO contracts, rock excavated from cuts may be used as material in embankment fills or as a source for aggregate production, provided that surplus quantities are available and that physical requirements for quality are met. Where there are multiple uses for large volumes of excavated rock on a project, any change in the quantity of available materials from the original design estimates has a significant impact on operations and materials management. For example, an error in the 1.5 bulking factor as little as 5% could result in a surplus or shortfall of more than 75,000 m^3 of rock material for any of the large contracts in the Parry Sound area.

The source of the 1.5 bulking factor value used for MTO work is not known. However, for the majority of MTO contracts involving rock excavation, typically less than 100,000 m^3, this value has been adequate. For such relatively small quantities, volumetric errors in the original design estimate are usually compensated for with extra rock being incorporated into embankment fills from outside the proposed excavation limits, i.e., overbreak from the walls and shattered rock from beneath the cut. Bulking factor values based on detailed records of specific material excavation removal and fill placement quantities from MTO construction projects are not available.

The first embankment built near Parry Sound, Ontario determined a bulking factor of 1.353. The second rock fill embankment was constructed at the Morrison Pit to confirm this value using a separate builder and different bedrock material.

Field Work

The Morrison Pit test embankment was constructed using granite, felsic gneiss and marble breccia obtained from a roadside rock cut excavation from ongoing highway construction on Highway 35, near Minden, Ontario (Figure 1). The work was done as part of MTO Northeastern Region Contract No. 2003-5002. The Morrison Pit was selected by the contractor for its proximity to the rock cut source as well as to take advantage of calibrated weigh scales for measuring the mass of rock used in the embankment. The test embankment was included as a lump sum item (Rock Bulking Factor) tendered in the contract documents under an item-specific Non Standard Special Provision that required an embankment built to current Ontario Provincial Standard Specifications (OPSS 102, OPSS 206 and OPSD 201.010). The contract was awarded in May 2003 but he construction of the test embankment did not start until May 2004 due to scheduling of the contractor's operations. The embankment was completed in June 2004.

The embankment volume was determined by surveying and the mass of the embankment was measured during its removal. Detailed ground surveys of the roadside rock cut before and after excavation were not taken, as this would only have provided limited information. The contract had a surplus of excavated rock, resulting in some of the excavated material being hauled to other locations within the work or wasted and not being incorporated into the embankment. Truck box measurements could not have been used for measuring quantities since individual rock volumes truckloads varied greatly.

Construction of the test embankment was separated from work along the highway right-of-way in order to better manage the disposition of all materials and simplify the tracking and measuring of the rock materials used. Under MTO construction contracts, rock made available from excavations becomes the property of the contractor who makes the decision to use the material as fill, crush it for aggregate production or dispose of it as surplus. Where there is insufficient material to complete the work, sources of additional rock are identified by the contractor. These options make it difficult to track and measure the general use of rock on a contract unless detailed surveys of all material excavation and placement operations are taken.

SITE LOCATION

The Morrison Pit, owned by Leveque Brothers Construction of Bancroft, Ontario, is located off Deep Bay Road in the Township of Lutterworth, County of Haliburton, Lot 24, Concession 7 (Figure 2). Within this location, the site selected for construction of the embankment was relatively flat with no significant projections or depressions and sufficiently large enough to allow access for construction vehicles and survey equipment. No additional preparation of the site was necessary.

BEDROCK GEOLOGY

The rock material was obtained from a rock cut widening located within the existing contract limits, approximately 200 m north of the Morrison Pit on Hwy 35 (Figure 3). Rock was excavated between stations 14+790 to 14+950 (Figure 4). The bedrock consists of interlayered granite, felsic gneiss and marble breccia (Figure 3) from the Bancroft Terrane of the Central Metasedimentary Belt in Grenville Province, Mesoproterozoic age, approximately 1270 to 1220 Ma (Easton, 1992). This site lies directly on granite-gneiss in fault contact with a marble tectonic breccia from the Denna Lake Structural Complex.

All rock used in the building of the embankment was taken from the same source as described above. Within the site limits of the excavation, the bedrock exhibited various stages of weathering. The first area to be excavated was composed of an extremely weathered granite-gneiss (Figure 5 and Figure 6). Much of this material was used during the initial construction of the embankment approach ramp but was considered unsuitable for additional construction of the main embankment. Following a site visit, the Contractor was instructed to discontinue using this material. The remainder of the embankment was constructed using the more competent bedrock located directly to the south of this location, which was of sufficient quality and strength for the needs of the project. Petrographic descriptions (LS-609) of the bedrock from this location indicate predominantly hard, unweathered granite and felsic gneiss with 30 % marble breccia and impure marble. There was also a small percentage (<2 %) of mafic gneiss and intermediate gneiss.

EMBANKMENT DESIGN

The minimum dimension requirements of the embankment were 40 m in length with the upper level surface a minimum of 3 m above the highest ground point. The upper surface was to be a minimum of 9 m in width, which is typical for a two-lane highway section. The overall embankment footprint was expected to be 60 m x 20 m, including the access ramp. An initial volume of 1600 m^3 of bulked rock fill was estimated for the embankment. This volume included allowances for sideslopes, surface crossfall and 10% overbuilding but did not include the volume of the access ramp.

Construction requirements of the embankment were according to Construction Specification for Grading (OPSS 206). Individual block size used in the rock fill could not exceed one third of the height of the fill vertically and one half of the height of the fill horizontally, which effectively limited the maximum block size to 1m^3. The final grade and sideslopes of the embankment were according to the standard drawing on Rock Grading (3% grade from centreline to the edge of the shoulder and 1.25:1 sideslopes, see Appendix B: OPSD 201.010).

INITIAL SURVEY – ORIGINAL GROUND

Prior to constructing the embankment, the long axis orientation was selected and an area 75 m x 25 m was outlined. Following this, initial surface elevations were taken on a 2 m x 2 m grid to establish the original ground level. The survey was carried out using a Sokkia 4100 Total Station and an SDR 33 Data Recorder on the prepared surface from Station 1+000 to

1+060 using a 2 m grid up to 14 m on each side of the centreline. The set up and survey took one day to complete. For reference, four benchmarks were established at various locations surrounding the embankment site.

EMBANKMENT CONSTRUCTION

Rock fill material was loaded from the blasting source with a CAT 330 B_L backhoe (Figure 7 and Figure 8) and hauled to the embankment site in a Volvo BM A30 and 2 Volvo A25C trucks (Figure 9). Approximately 15-20 loads of material were placed in the embankment after each blasting operation took place. Initial construction began by building the access ramp to allow equipment to get to final grade. The finished length of the ramp was approximately 12 m and took 1 day to complete. The remainder of the embankment was constructed by end-dumping material in a continuous single lift (minimum height of 3 m) Figure 10, which was graded into place using a CAT $D6R_{XL}$ (Figure 11). Compaction of the embankment took place under the repetitive loading action of the rock trucks and the bulldozer movements. The A25 truck has a net weight of 16.9 tonnes with a payload capacity of 22.5 tonnes. The A30 truck has a net weight of 20 tonnes with a payload capacity of 17 tonnes. The CAT $D6R_{XL}$ has an operating weight of 18.7 tonnes and a flywheel power of 138 kW. Specific compaction equipment was not used.

The construction of the embankment was completed in 6 working days over a 2-week period. Construction of the embankment was interrupted as equipment was used for several different operations within the contract, which affected the rock excavation scheduling and access to materials. The blasting, hauling and placement of material took 5 working days to complete (Figure 12) with an additional day for final trimming of the sideslopes and top surface. All sideslopes of the embankment (other than the ramp incline) were trimmed to 1.25:1 (Figure 13) using a Hitachi 330 Excavator. Oversized material that could not be accommodated in the embankment was removed. The final upper surface of the embankment was brought to a 3% crossfall. Additional finer material from the blasting source was placed on the surface for chinking. The weather was dry and sunny for the majority of the project and the embankment materials remained in a dry, drained condition.

INTERMEDIATE SURVEY – EMBANKMENT SURFACE

Following completion of the embankment, a second detailed ground elevation survey was conducted using a single survey crew (Figure 14). The embankment was surveyed on a 2 m x 2 m grid except for the breakpoints along the embankment shoulders, side slopes and toe where a single reading was taken at the midpoint of the slope between the shoulder and the toe at each section. An additional reading and cross-section was taken at Station 0+998 as the area looked slightly disturbed after the construction was complete. The intermediate survey took half a day to complete.

EMBANKMENT REMOVAL

The embankment was excavated following the intermediate survey during which, the mass of materials making up the embankment was measured. The removal and weighing of the embankment was performed using a CAT 980G loader (bucket capacity of approximately

7.5 tonnes) equipped with a built-in VEI Millenium V.1.4 scale for measuring the weight of each load (Figure 15). All removed material was surplus to the contract requirements and was placed in a waste pile within the pit.

Table 1: Calibration Data for VEI Millenium vs. Platform Scales

Trial	Ticket Number	Loader: VEI Millenium Scale (Tonnes)	Quarry Platform Scale (Tonnes)	Difference (Kg)	Difference (Percent)
1	8075	19.36	19.33	30	+0.16%
2	8119	19.06	19.12	60	-0.31%
3	8202	20.56	20.20	360	+1.78%
4	8224	20.24	20.37	130	-0.64%

Average = +0.25%

The loader scale was calibrated against the certified platform scales located elsewhere in the pit. To perform the calibration, a tandem truck was loaded with stockpiled granular base aggregate and the accumulated mass was measured on the platform scale and compared with the mass recorded by the loader scale. Separate calibrations were made at the beginning and at the end of each day's operations with four calibrations made in total. Calibration data is presented in (Table 1). Differences between the loader scale and the platform scale appear to be random and do not demonstrate any trend. On average, the loader scale was accurate to within 0.25% of the actual load.

The excavation and removal of the embankment material took place over a 2½ day period and used approximately 500 loads of weighed material. Cumulative weights from each load were continuously displayed by the loader, which had the capacity to indicate a maximum accumulated weight of 3,000 tonnes. During the embankment removal, the loader was utilized for various other operations in the pit. When this occurred, the loader scale was deactivated and restarted upon resuming the embankment excavation. Accumulated weights were recorded each time the loader scale was reset to zero and the final accumulated weight was determined once the excavation was complete.

FINAL SURVEY – FINAL GROUND

Following removal of the embankment a final detailed ground elevation survey, based on the original 2 m x 2 m grid, was conducted. This survey was used to determine the total volume of the embankment, including the volume of additional materials removed from the original ground beneath the embankment.

Measurements

EMBANKMENT VOLUME

Volume measurements were determined from the processed data reported directly from the three elevation surveys. Measured volumes are given below in Table 2. Two volumes were determined: Volume A (V_a) is the volume of the finished embankment as built over original ground. This value is calculated from the initial survey (S_1) prior to construction and the intermediate embankment survey (S_2) following construction. Volume B (V_b) is the volume of materials removed and is calculated from the difference between the finished embankment survey (S_2) and the final ground survey (S_3) immediately following removal.

Table 2: Embankment Volume Measurements

Surveyed volumes		
Volume A (V_a)	Volume of constructed embankment Based on: Δ S_1, S_2; Fill 1863, Cut 13 (1863 –15)	1850 m^3
Volume B (V_b)	Volume of excavated material Based on: Δ S_2, S_3; Fill 3, Cut 1918 (1918-3)	1915 m^3
Difference (1)	Volume of over excavated material Based on: (V_b -V_a)	65 m^3
Difference (2)	Volume of over excavated material Based on: Δ S_1, S_3; Fill 2, Cut 79 (79-2)	77 m^3

There is a 12 m^3 discrepancy (0.6 %) between the two volumes of over excavated material calculated in Table 2. Averaging this error gives approximately 71 m^3 that represents the volume of additional materials excavated from beneath the embankment. Averaging errors based on where the actual survey points were taken along the surface of the embankment are considered minimal.

EMBANKMENT MASS

The mass of materials weighed during the removal stage is summarized below in Table 3.

Table 3: Mass measurements during removal

Scroll	Weights (tonnes)
1	1027.16
2	1566.80
3	735.18
4	460.68
Total:	**3789.82**

If the volumetric difference noted above (~71 m^3) is assumed as over-excavation, the mass of the constructed embankment may be adjusted by subtracting the mass of compacted

granular aggregate, using an approximate density of 2.2 t/m^3. Thus, the actual mass of the embankment adjusted for over excavation becomes 3789.82 – (71 x 2.2) = 3789.82 – 156.2 = **3633.6 tonnes**. Since construction and removal of the embankment was carried out in dry weather, no correction due to the presence of excessive precipitation moisture has been applied.

EMBANKMENT DENSITY

The density of the embankment (bulk rock fill density) can be calculated as mass per unit volume using various measurements. Two different calculations were made to compare the densities of the test embankment based on measurements taken from different points in the construction phase. Comparative calculations for densities of the test embankment are given in Table 4. The first calculation uses the adjusted mass value corrected for over excavation and the volume V_a that represents the volume of material placed in the embankment. This calculation gives the density value used in the bulking factor calculation since it represents the actual mass and volume of the embankment before excavation. The second calculation is for comparative purposes only. It uses the mass and volume of material excavated from the embankment that includes the additional material from the pit floor. Densities are expressed as relative densities therefore the units used are tonnes per cubic meter (t/m^3).

Table 4: Embankment Bulk Density (t/m^3)

	Mass (tonnes)	Volume (m^3)	Density (t/m^3)
Based on adjusted mass	3633.6*	1850 (V_a)	1.964
Based on total mass	3789.8	1915 (V_b)	1.979

* (Corrected for over excavation)

By comparison, these embankment densities are similar to but lower than embankment densities calculated for the project at Parry Sound (2.081 t/m^3 and 2.096 t/m^3 respectively).

BEDROCK DENSITY

The density of the bedrock materials used in the embankment construction was determined using reliable laboratory methods. Seventy-four hand specimens (ranging from 5-20 cm diameter) were randomly selected from the rock fill placed in the embankment. The density of each sample was determined using test method LS-604, which is based on the principle that a buoyant force on a submerged object is equal to the weight of the fluid that is displaced by the object (Archimedes Principle). This means that the difference between the dry and wet mass of the rock sample will equal the volume of the sample and its density can be determined using the following formula:

$$Density = \frac{m_{dry} - m_{wet}}{m_{dry}}$$

Where m_{dry} = *dry mass of sample* and m_{wet} = *wet mass of sample*

An average density of **2.703 t/m^3** was calculated from the 74 samples. The sorted results can

be found in Table 5:

Table 5: Bedrock Density

Sample	Density (t/m^3)	Sample	Density (t/m^3)	Sample	Density (t/m^3)	Sample	Density (t/m^3)	Sample	Density (t/m^3)
1	2.562	16	2.628	31	2.666	46	2.704	61	2.790
2	2.573	17	2.631	32	2.677	47	2.707	62	2.793
3	2.600	18	2.633	33	2.680	48	2.711	63	2.798
4	2.607	19	2.634	34	2.684	49	2.718	64	2.803
5	2.610	20	2.637	35	2.685	50	2.718	65	2.808
6	2.611	21	2.640	36	2.686	51	2.721	66	2.816
7	2.612	22	2.642	37	2.689	52	2.722	67	2.827
8	2.616	23	2.643	38	2.689	53	2.730	68	2.844
9	2.618	24	2.644	39	2.689	54	2.740	69	2.858
10	2.621	25	2.644	40	2.692	55	2.747	70	2.861
11	2.624	26	2.645	41	2.692	56	2.749	71	2.866
12	2.625	27	2.651	42	2.696	57	2.751	72	2.890
13	2.626	28	2.654	43	2.699	58	2.762	73	2.906
14	2.628	29	2.659	44	2.700	59	2.764	74	2.989
15	2.628	30	2.663	45	2.702	60	2.769		

Average Density = 2.703 t/m^3

A histogram showing the distribution of the values given above can be found as Figure 19. The distribution appears normal with a slight skewness towards the denser rock types. The standard deviation of the distribution is 0.086.

The method used for determination of densities of individual samples as given above does not account for existing joints, fractures and other voids present within the bedrock mass. As such, the average density determined from experimental methods may not accurately measure the overall bulk density of the bedrock materials. A true value cannot be determined without directly detailed measurements of the mass and volume of the excavated area. Since this project involved an on-going construction process where the contractor had to make daily decisions on the movement and disposition of materials, such a detailed survey and mass measurement at the source was impractical. Qualitatively, the in-situ bedrock was observed to be massive with little or no fractures, joints were extremely wide spaced, very tight apertures with no infilling materials. For the purposes of this experiment, the average density of samples taken from materials within the embankment is considered practical and sufficient for the purpose.

BULKING FACTOR CALCULATION

Calculation for the bulking factor is based on the ratio of the average density of the embankment to the average density of the bedrock and is tabulated below in Table 6.

Table 6: Calculated Bulking Factor

Embankment density (t/m^3)	Bedrock density (t/m^3)	Bulking Factor
1.964	2.703	**1.376**

Based on the volume of the constructed embankment and the embankment mass adjusted for

over excavation, the bulking factor is determined to be 1.376.

Discussion

The experimentally determined bulking factor for end-dumped, partially compacted rock fill was calculated to be 1.376. This value is based on detailed field measurements of the mass and volume of a constructed rock fill embankment compared to the mass and volume of the in-situ bedrock prior to excavation. The bulking factor calculated by this exercise is significantly less than the standard value of 1.5 used in MTO highway design. The project was undertaken in a carefully controlled environment.

For the final calculations, several assumptions were made. Firstly, the calculation of the embankment density, including the volume calculation and a mass correction for over-excavated material during its removal was considered. Three detailed ground elevation surveys were taken during the study. The first survey was taken to establish elevation of original ground. Comparison with the final survey taken following removal was used to determine the volume of additional excavated material. Without the initial survey, only a single volume for the embankment would be recorded, resulting in an embankment density of 1.979 t/m^3. The bulking factor value calculated using this volume would have been of 1.367. The average bulking factor from these determinations is 1.372.

The next assumption involves the correction for the over excavated material, which consisted of compacted granular road base material derived from the pit crushing operations. A value of 2.2 t/m^3 was used to calculate the adjusted mass for this material, which is based on density determinations reported from compaction testing of aggregates meeting the granular base gradation requirements of OPSS 1010 (Granular A). MTO designers currently use a theoretical conversion factor of 2.4 t/m^3 for Granular A, however, the lower value was used for this project since it is based on numerous field and laboratory tests reported from construction projects for this type of bedrock. The last major assumption is the in-situ density of the bedrock. A value of 2.703 t/m^3 was used which is consistent with rock types encountered at this location.

The rock fill used in the embankment was placed and compacted in a single lift, approximately 3 m in height. Future considerations for reducing embankment settlements on MTO projects include placing of rock fill in maximum 1.5 m lifts and compacting each lift prior to the addition of any subsequent material. Compaction for this type of operation is to be carried out by 6 to 8 passes of a track type tractor-dozer with a minimum flywheel power of 200kW. These compaction requirements were not included in the construction of the embankment used to determine a bulking factor due to the relative small height and size of the embankment. In practical terms, the construction of an embankment using thinner lifts and more powerful, heavier equipment would result in a slightly denser rock fill, thus lowering the bulking factor value.

Other variables that may have affected the rock bulking factor value include size distribution of the various rock fragments, which influences the overall packing density of the fill. Well-graded materials would result in increased fewer unfilled voids between larger diameter

fragments while poorly graded fills would contain large void spaces. Factors affecting rock fragment grading and packing density include blast design, powder factor, joint spacing of the bedrock, segregation, rock particle shape and void anomalies within the fill.

Conclusions

The results of this project carried out near Minden, Ontario determined a rock bulking factor of 1.376, which supplements the value of 1.353 previously obtained in a similar project carried out near Parry Sound, Ontario. The construction methods for both projects were identical and the final results indicate a rock bulking factor significantly lower than the current design value of 1.5 used by MTO. The results from the two projects are summarized in Table 7.

Table 7: Summary of Rock Bulking Factor Projects

Project	Bedrock	Embankment Density (t/m^3)	Bedrock Density (t/m^3)	Bulking Factor
Parry Sound (Foley Quarry)	mafic granite, granite gneiss, amphibolite gneiss	2.081	2.816	1.353
Minden (Morrison Pit)	granite, felsic gneiss, marble breccia	1.964	2.703	1.376
	Difference	0.116	0.113	0.023
	Difference (%)	5.6%	4.0%	1.7%
	Average	2.023	2.760	1.365

The difference between the two bulking factor values of 1.7% is most likely related to the particles size distribution and packing density within each embankment. Variations between the two projects include the type of rock used to build the embankment and the construction schedule. In the Foley Quarry (Parry Sound), a dense, mafic rock was used whereas at the Morrison Pit (Minden), a lighter, felsic rock was encountered. In general, the bedrock types found within these two projects are representative of the possible range in materials found throughout the Canadian Shield in Ontario. What is not accounted for is the wide variability in character and quality of Ontario bedrock, including spacing and condition of discontinuities, e.g., joints and fractures, and overall strength and durability.

The Parry Sound project only took a few days to complete since the work was tendered as an individual contract specifically for the completion of the embankment study. The excavated rock was extracted from the production stream for crushed granular base material. In comparison, the Minden area project was tendered as a separate item within a capital contract (Contract 2003-5002) that took place as part of the roadway improvements along Highway 35. In this case, work was heavily dependant on the contractor's schedule such that construction of the embankment took several weeks to complete. As a result, bedrock from the Parry Sound project was more consistent as it came from relatively homogeneous bedrock within an operating quarry. Bedrock from the Minden was more variable as it included the highly weathered granite-gneiss excavated during the initial phase of

construction.

On any given project, there are many different factors that influence the actual bulking factor for rock such as the variability of the rock type (mineral composition), the in-situ density of the bedrock mass (jointing and fractures, presence of voids etc.), the bulk density of the rock fill (blast fragmentation, particle size distribution, segregation, particle shape, moisture), as well as construction methods (layer thickness, compaction effort). Regardless of the true value of this parameter, project designers (and contractors) need a reasonable estimate for this value when planning projects.

Based on the values determined from the two projects, the Materials Engineering and Research Office, MTO recommended that a bulking factor of 1.35 be used for new construction projects involving rock excavation within Ontario. This value is not an average of the two factors but a design value for estimation purposes based on the two experimental determinations, taking into account possible errors in assumptions and measurement as well as future construction methodology limiting lift thickness within rock fill embankments to a maximum of 1.5 m. Recommendations were made to apply this new bulking factor to most igneous and metamorphic Precambrian rocks of the Canadian Shield and hard, durable Palaeozoic carbonates and sandstones of southern Ontario. For other rock types such as shale, shaley limestone, chlorite schist and deeply weathered rock, it is probable that a lower bulking factor will be required.

As a follow up to the initial recommendations, a memo from the Chief Engineer was issued instructing highway designers to use a rock bulking factor value of 1.35 when estimating quantities (see Appendix C).

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LS-609 Petrographic Analysis of Coarse Aggregate

Ontario Provincial Standards and Specifications (OPSS)
OPSS 206 (1993) Construction Specification for Grading
OPSS 102 (1992) Weighing of Materials

Ontario Provincial Standard Drawings (OPSD)
OPSD 201.010 (1999) Rock Grading – Undivided Highway

Appendix A: Figures

Figure 1 – Location of project area near Minden, Ontario.

Figure 2 – Location of Morrison Pit near Moore Falls, approximately 17 km south of Minden.

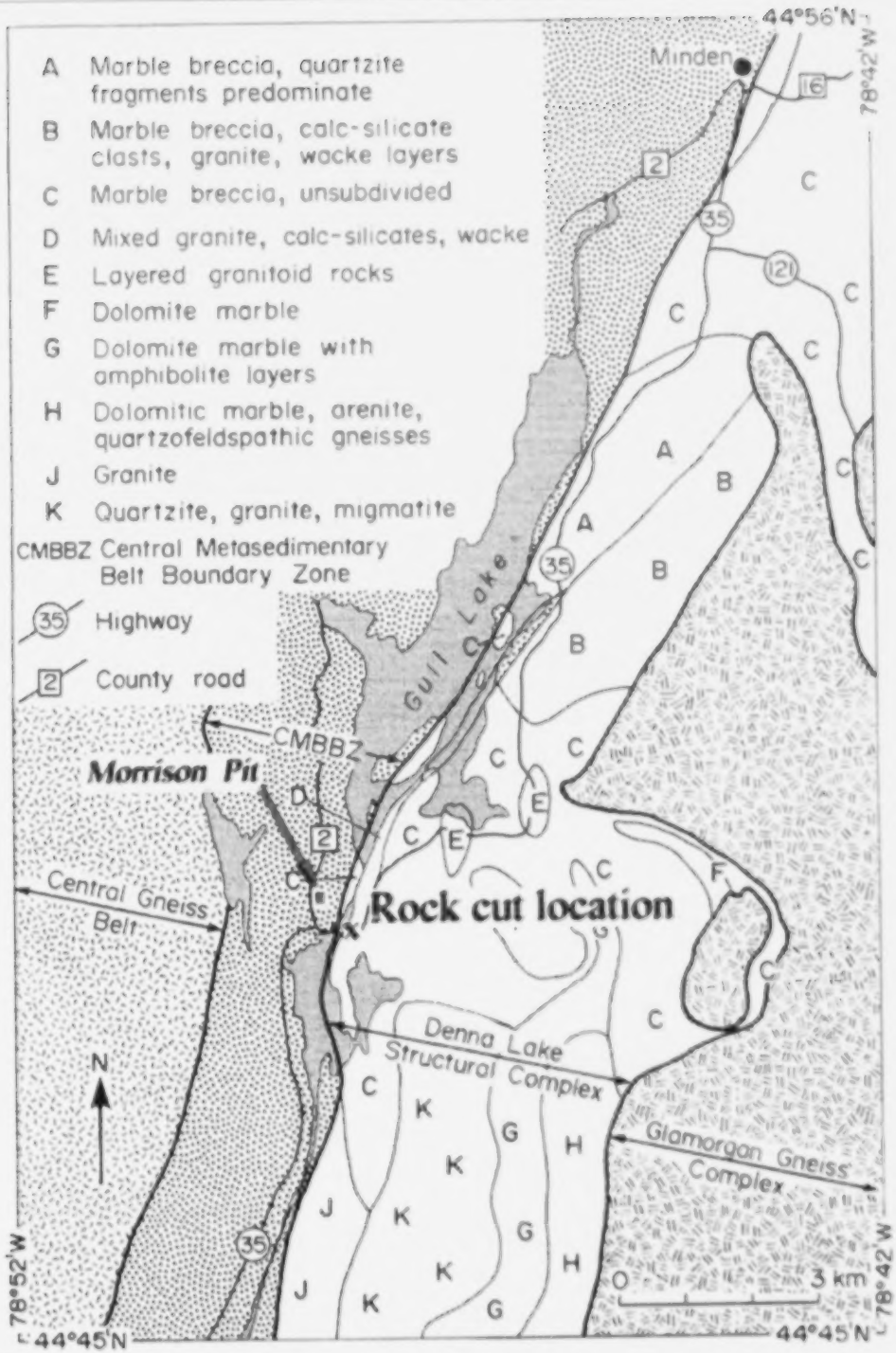

Figure 3 – Bedrock geology of the project showing locations of the rock cut used as a material source and the Morrison Pit (after Easton, 1992)

Figure 4 – Source material for the embankment was taken from bedrock excavated from this rock cut on Hwy 35.

Figure 5 – Initial construction of the test embankment began with a highly weathered granite-gneiss immediately north of the rock location shown in Figure 4 and Figure 7

Figure 6 – Close-up view of the weathered granite-gneiss shown above. This rock was used in construction of the access ramp during initial stages of the embankment construction.

Figure 7 – View of blasted rock at the site of excavation showing general block size distribution of the muck pile.

Figure 8 – Excavation of source materials using a CAT 330 B_L backhoe into Volvo A25C rock truck.

Figure 9 – Materials were transported to the embankment construction site, end-dumped in a single lift and spread by bulldozer.

Figure 10 – View of partially constructed test embankment within Morrison Pit. Access ramp on the right is approximately 15m long

Figure 11 – Spreading of materials and grading was accomplished with a CAT D6R XL. Note segregation along leading outside edge of embankment. Blocks larger than 1 m diameter (1/3 height of embankment) were removed.

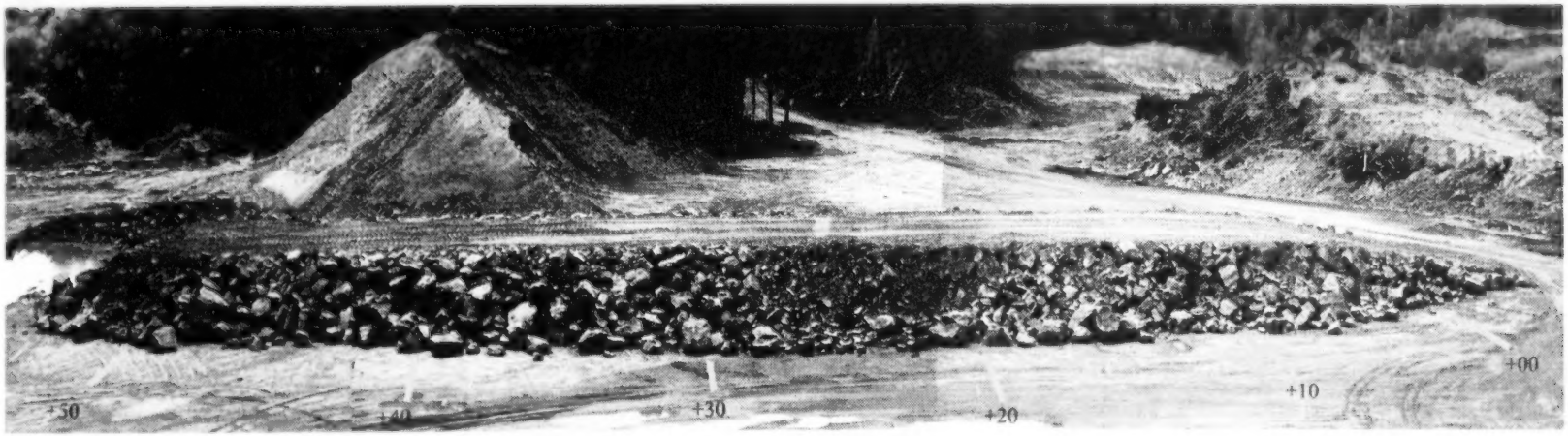

Figure 12 – Photocomposition of embankment near completion with approximate stations for scale.

Figure 13 – View of embankment side slopes, graded to meet requirements of OPSD 201.010.

Figure 14 – Survey being conducted following completion of the embankment to calculate initial volume of materials.

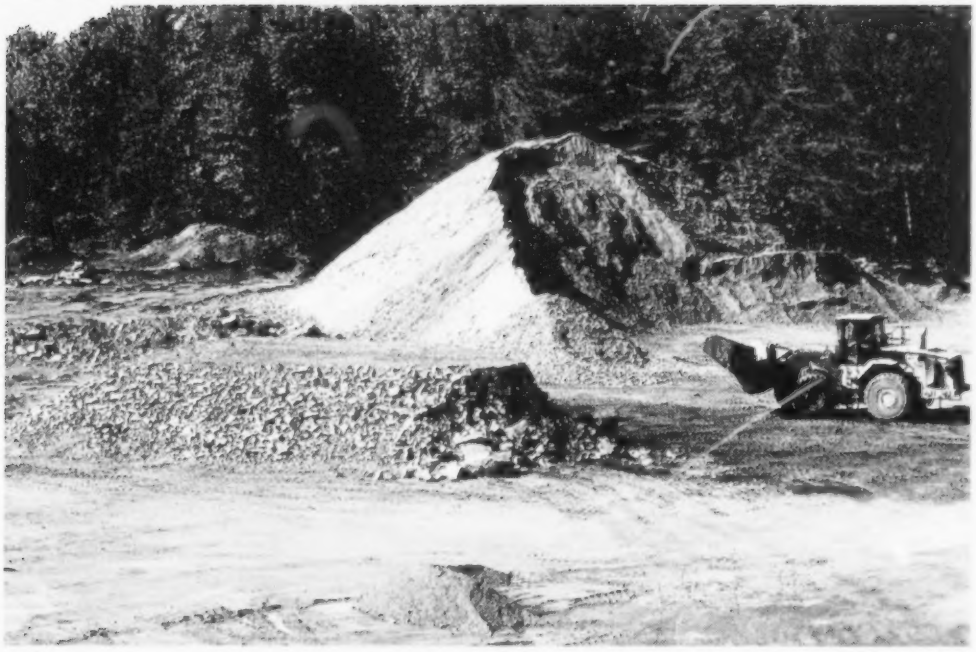

Figure 15 – Removal of embankment by CAT 980G loader. Materials were weighed using on-board scales calibrated daily against the pit scales.

Figure 16 – Close-up of embankment removal. The operator recorded cumulative masses of each load.

Figure 17 – Embankment near complete excavation. Materials were removed as close to original ground elevation as possible. A final survey was completed to determine volume of materials removed.

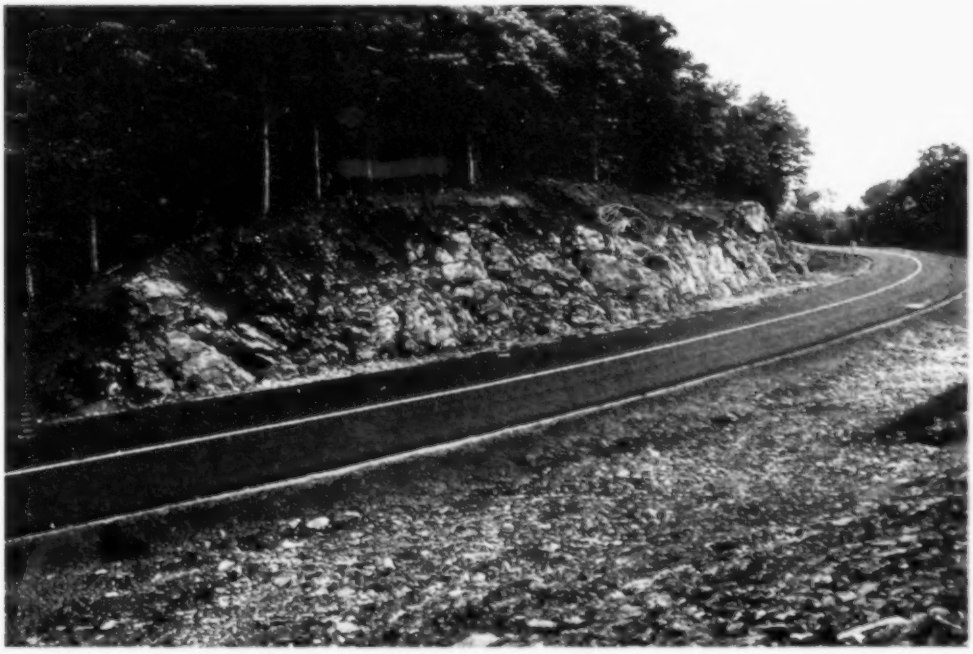

Figure 18 – View of finished rock cut after final grading and hydro seeding.

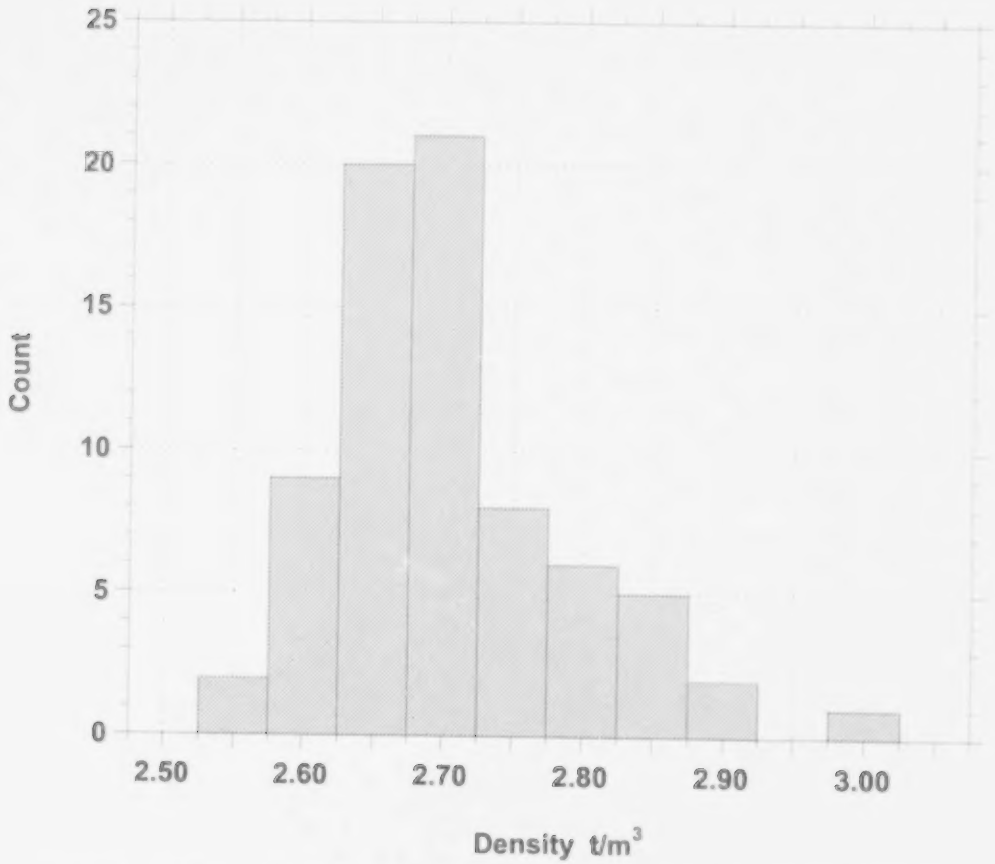

Figure 19 – Histogram of individual dry density values of 74 random samples collected from the finished embankment. The average density of the samples is 2.703 t/m^3.

Appendix B: OPSD 201.010

Ontario Provincial Standard Drawing (OPSD) used for construction of undivided highway rock fill embankments in Ontario.

Appendix C: Memo Sept 14, 2004

Ontario

Ministry of Transportation | Ministère des Transports

Office of the Chief Engineer
Engineering Standards Branch
301 St Paul St, 2nd Floor
St Catharines, ON L2R 7R4
Tel: (905) 704-2083 Fax: (905) 704-2055

MEMORANDUM

DATE: September 14, 2004

TO: Roger Hanmer, Osmo Ramakko, Larry Lambert, Brian Peltier, Kathryn Moore

FROM: Raymond J. Mantha

RE: Change to Rock Bulking Factor used in Highway Design

The Materials Engineering Research Office (MERO) recently completed a project to accurately quantify a bulking factor for rock fill. The experimental rock bulking factor value was obtained by constructing two separate embankments, one using amphibolite gneiss and the other composed of granite, felsic gneiss and marble. The density of the in-situ bedrock to the bulked density of blasted rock within each embankment was compared.

A bulking factor value of 1.35 was determined for both test sites, which is considerably less than the value of 1.5 currently used for estimating. MERO is recommending that the lower value be used for planning and design activities to estimate rock material quantities.

Highway designers should use a bulking factor value of 1.35, effective immediately, for all hard bedrock types when estimating rock quantities. From time to time, shale, shaley limestone (southern Ontario, Manitoulin and St. Joseph Islands and New Liskeard area), chlorite schist, and deeply weathered rock (northwestern Ontario) may be encountered. For these bedrock types, a lower bulking factor than 1.35 may be required, in which case the Soils and Aggregates Section should be consulted.

Jobs currently under design should use this revised bulking factor if the rock fill quantities are significant. Stockpiled jobs should be examined to see if use of a value of 1.35 will result in a significant under-run in rock for fill and granulars. If so, consideration should be given to advising the contractor of potential MTO sources for additional rock including, when appropriate, within the ROW. On all jobs consideration should be given, in consultation with the Geotechnical Section, to the potential sources of supply of aggregates and rock embankment materials (See the "Summary of existing ministry and provincial policy on making available non-commercial sources of aggregate for MTO work" - on the MERO intranet site under "documents").

Raymond J. Mantha, P.Eng.
Chief Engineer

cc: C. Hennum, S. Cheng, C. Rogers, L. Poltano, J. Buck, G. Todd, B. Van Veen, S. Senior, M. Trickey, M. Maclean, C. McKercher, K. Williams, C. Lucas, B. Tharmabala, H. Walker, K. Bentley, G. Chaput, P. Verok, G. Castillo, P. Makula, R. Hogan

Appendix D: Published Rock Properties

The following tables are reproduced from Materials Engineering and Research Office Report MERO-004 (Senior et al, 2003).

Table D - 1. Bulking factors used by other jurisdictions (MTO, 2000)

Jurisdiction	Bulking factor	Comments
Newfoundland	1.2 to 1.25	No set assumption, up to designer
New Brunswick	Shale 1.1 to 1.25 Granite 1.4 to 1.5	
British Columbia	No set factor	1.7 suggested
New York	No set factor	Assumptions up to contractor
Washington State	Granite 1.72 (assumed)	Based on data from Excavation Handbook (Church, 1981)
Maine (DOT) Highway Design Guide	1.33	Value for rock excavation for common borrow (pers. comm.).

Table D - 2. Average weights of various rock types (ETI, 1980)

Material	SG	Density	
		Solid	Broken
Basalt	2.80 – 3.0	3044	2002
Coal - Anthracite	1.3 – 1.8	1602	1041
Coal - Bituminous	1.2 – 1.5	1362	881
Diabase	2.6 – 3.0	2803	1842
Diorite	2.8 – 3.0	2964	1922
Dolomite	2.8 – 2.9	2883	1842
Gneiss	2.6 – 2.9	2883	1842
Granite	2.6 – 2.9	2723	1762
Gypsum	2.3 – 3.3	2803	1842
Hematite	4.5 – 5.3	4886	3204
Limestone	2.4 – 2.9	2643	1682
Limonite	3.6 – 4.0	3764	2483
Magnesite	3.0 – 3.2	3204	2002
Magnetite	4.9 – 5.2	5046	3284
Marble	2.1 – 2.9	2483	1602
Mica-schist	2.5 – 2.9	2723	1762
Porphyry	2.5 – 2.6	2563	1682
Quartzite	2.0 – 2.8	2563	1682
Salt - rock	2.1 – 2.6	2323	1522
Sandstone	2.0 – 2.8	2403	1522
Shale	2.4 – 2.8	2563	1682
Silica sand	2.2 – 2.8	2563	1682
Slate	2.5 – 2.8	2723	1762
Talc	2.6 – 2.8	2643	1762
Trap rock	2.6 – 3.0	2803	1842

Table D - 3. Average weights of various rock types (APAO, 2000)

Materials		Bulk Unit Wt (kg/m^3)
Dolomite	Broken	1742
	Solid	2895
Gypsum	Broken	1809
	Crushed	1600
	Solid	2783
Limestone	Broken	1555
	Solid	2607
Sandstone	Broken	1511
	Solid	2319
Shale	Broken	1579
	Solid	2666
Slate	Broken	1653
	Solid	2687

Note: Above weights may vary in accordance with moisture content, grain size, degree of compaction etc.

Table D - 4. Weights of various rock types (Hoek & Bray, 1981)

Rock Type	Bulk Unit Wt (Kg/m^3)
Intact rock:	
Hard igneous rock granite, basalt, porphyry	2550 - 3060
Metamorphic rock quartzite, gneiss, slate	2550 - 2860
Hard sedimentary rock limestone, dolostone sandstone,	2350 - 2860
Soft sedimentary rock sandstone, coal, chalk, shale	1735 – 2350
Blasted, Broken Rock:	
Basalt	2245
Chalk	1326
Granite	2040
Limestone	1938
Sandstone	1735
Shale	2040

Table D - 5. Weights of various rock types (Carmichael, 1981)

Rock Type	Bulk Unit Wt (Kg/m^3)	
	from	to
Granite	2571	2800
Granodiorite	2740	2689
Gabbro	3000	3190
Gneiss	2650	3360
Schist	2490	3028
Dolomite	2400	2800
Greywacke	2500	-
Limestone	1790	2853
Shale	2044	2738
Sandstone	2015	2650

Table D - 6. Bulking/ Shrinkage Factors for various materials (University of Durham, 1997)

Material	Bulk Density (Mg/m^3)	Bulking Factor	Shrinkage Factor
Clay (Low PI)	1.65	1.30	-
Clay (High PI)	2.10	1.40	0.90
Clay and Gravel	1.80	1.35	-
Sand	2.00	1.05	0.89
Sand & Gravel	1.95	1.15	-
Gravel	2.10	1.05	0.97
Chalk	1.85	1.50	0.97
Shales	2.35	1.50	1.33
Limestone	2.60	1.63	1.36
Sandstone (Porous)	2.50	1.60	-
Sandstone (cemented)	2.65	1.61	1.34
Basalt	2.95	1.64	1.36
Granite	2.41	1.72	1.33

Note: **Bulking factor** is defined as the increase in volume of material created by excavation:
= Volume after Excavation/Volume before Excavation
Shrinkage factor is defined for the compaction of a material at its final destination:
= Volume after Compaction/Volume before Excavation